Electric Propulsion Induced Secondary Mass Spectroscopy (EPI-SMS)

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Introduction: Recently, missions such as Deep Space 1 and Dawn have utilized electric propulsion (EP) which utilizes an accelerated, high energy collimated beam of Xe+ ions to propel deep space missions to their target bodies. EP has a larger specific impulse (ISP) over chemical propulsion, resulting in its selection for propulsion of choice to small bodies, where low orbits of < 10 km are possible. The energies of the Xe+ propellant in EP are typically 0.5-3keV [1]; it has been reliably used for decades in laboratory sputtering experiments to eject material from the top microns of a targeted surface [2, 3, 4]. Material, such as minerals, ices, salts, etc, that are sputtered can then be analyzed using an open source mass spectrometer aboard the spacecraft [5]. Thus, electric propulsion exhaust can assist in the determination of detailed surface composition of atmosphere-less bodies by electric propulsion induced secondary mass spectroscopy (EPI-SMS). Figure 1 is a graphical representation of the EPI-SMS process.

Historically, most compositional analysis of small body surfaces has been done remotely by analyzing reflection/nuclear spectra or by their dielectric properties in radar sounding. However, neither provides direct measurement that can unambiguously constrain the surface composition and most importantly, the nature of second-phase impurities [6]. Surface systems, such as landers, may contain payloads and spectrometers to provide local detailed analysis at the surface – however these are risky and cost prohibitive for many missions. Touch-and-go sample acquisition methods are risky and require complex autonomous operations. We propose EPI-SMS as a means to complement remote spectroscopy while also providing in-situ surface samples without a landed system. By virtue of its versatile operation, EPI-SMS can be used to characterize surface composition, determine second-phase impurities, and isotopic ratio determination for a variety of science goals from astrobiology to the surface weathering in regolith safely from orbit.

EPI-SMS operation has two high-level requirements: an EP propellant system, and an open source mass spectrometer. EPI-SMS falls within reach of Discovery or New Frontiers missions without much additional risk or cost in development. For these lower cost missions, landing and near surface operations (<100m) results in raised costs and risks that make direct surface sampling infeasible without significant reductions in other scientific investigations. EPI-SMS provides a low risk and low cost technique to obtain in-situ surface samples that cannot otherwise be obtained.

1 keV Xe ions have been shown to generate high sputtering yields in metallic substrates, whose lattices have higher binding potentials than small body surfaces like ices [3, 4]. Using these yields, first-order calculations predict that EPI-SMS will yield 1 keV Xe ions have been shown to generate high sputtering yields in metallic substrates, whose lattices have higher binding potentials than small body surfaces like ices [3,4]. Using these yields, first-order calculations predict that EPI-SMS will yield high signal-to-noise at altitudes >10 km with both electrostatic and Hall thrusters.

Laboratory Methods: We are currently planning two different experiments to determine the nature of the sputtering products and also to validate EPI-SMS in a flight-like environment.

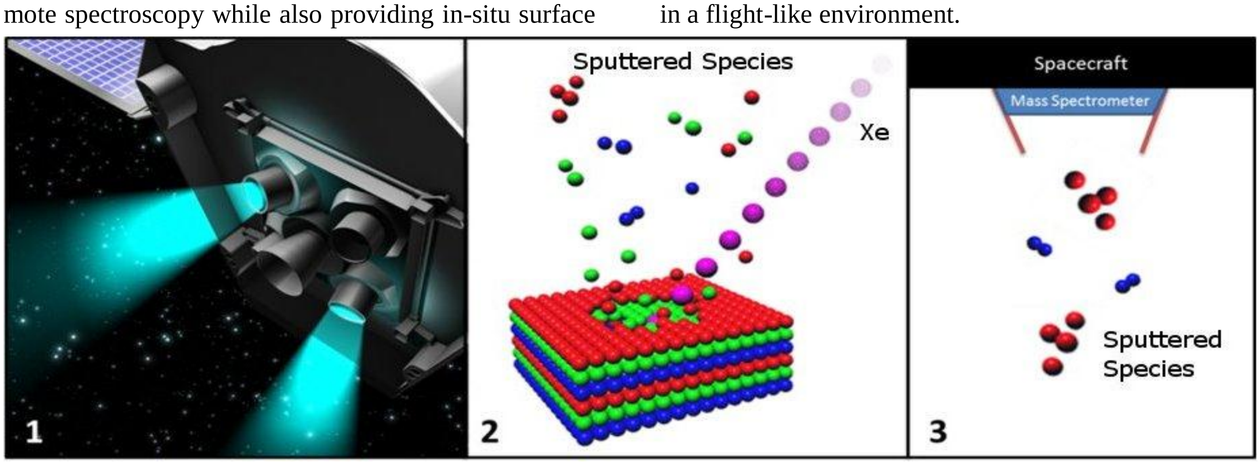

Figure 1 EPI-SMS Operation. 1. Spacecraft EP accelerates high energy Xe^+ toward body surface. 2. Xe^+ ions impinge on surface, sputtering species with 1-10 eV kinetic energy. 3. Sputter species arrive at spacecraft mass spectrometery for

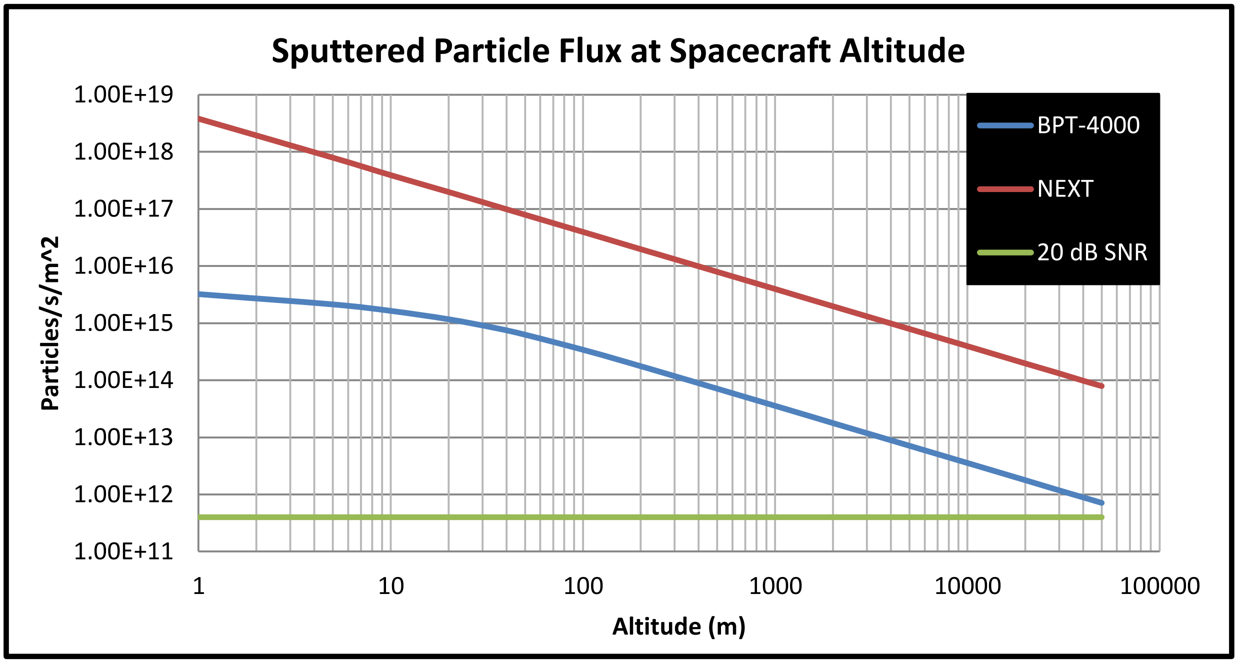

Figure 2 Expected EPI-SMS flux as function of altitude and electric propulsion type (BPT-4000, NEXT) operating with nadir pointing at full power on a MgO surface [7].

The first will be done at the Caltech Scattering Laboratory (CSL). CSL is capable of determining sputtered product chemical, kinetic, and spatial distributions while depositing Xe+ up to ~ 1000 keV with very narrow energy spreads (5 eV FWHM). This falls within expected performance of both Hall-effect and electrostatic ion thrusters. The laboratory ion gun will be used to simulate the ion energies and current densities of the different EP types operated at different altitudes. This experiment will be conducted with simulant rocky and icy surfaces. The results of this experiment will inform lower level operational requirements for maximizing yield and reducing risk.

Flight-like testing will be conducted at the JPL Electric Propulsion Laboratory in the 16' long High Bay chamber. This experiment will use engineering units of EP systems and residual gas analyzers (RGAs), used in place of a flight-like mass spectrometer in the experiment, with spacecraft-like separations . Plates of rocky simulants will be located opposite of the EP unit and RGA in the chamber. EP thrusting will generate a sputtered plume and dust, the latter which will be measured by witness plates in the chamber. The EP operation will also generate a plasma cloud around the EP system which will itself be modeled by EPIC and studied. The results of this experiment will lead to a better understand of the local plasma environment, surface charging, and instrument placement.

Anticipated Results: Preliminary study of EPI-SMS shows significant particle fluxes at orbit at a variety of altitudes and with two different electric propulsion types as illustrated in Figure 2. Figure 2 is an illustration of the solid angle sputtering calculation to determine the count rate of a mass spectrometer in an EPI-SMS experiment. However, this calculation is highly idealized and further study is required to better kinetic, spatial, and chemical distributions for various small body surfaces.

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